ZAMBIA: Long-Term Generation Expansion Study

EXECUTIVE SUMMARY

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The objective of this study is to analyze possible long-term development options of the Zambian electric power system in the period up to 2015. The analysis involved the hydro operations studies of the Zambezi river basin and the systems planning studies for the least-cost generation expansion planning. Two well-known and widely accepted computer models were used in the analysis: PC-VALORAGUA model for the hydro operations and optimization studies and the WASP-III Plus model for the optimization of long-term system development. The WASP-III Plus model is a part of the Argonne National Laboratory's Energy and Power Evaluation Model (ENPEP).

The analysis was conducted in close collaboration with the Zambia Electricity Supply Corporation (ZESCO). On the initiative from The World Bank, the sponsor of the study, ZESCO formed a team of experts that participated in the analysis and were trained in the use of computer models. Both models were transferred to ZESCO free of charge and installed on several computers in the ZESCO corporate offices in Lusaka. In September-October 1995, two members of the ZESCO National Team participated in a 4-week training course at Argonne National Laboratory near Chicago, U.S.A., focusing on the long-term system expansion planning using the WASP and VALORAGUA models.

The hydropower operations studies were performed for the whole Zambezi river basin, including the full installation of the Kariba power station, and the Cahora Bassa hydro power station in Mozambique. The analysis also included possible future projects such as Itezhi-Tezhi, Kafue Gorge Lower, and Batoka Gorge power stations. As hydropower operations studies served to determine the operational characteristics of the existing and future hydro power plants, it was necessary to simulate the whole Zambezi river basin in order to take into account all interactions and mutual influences between the hydro power plants. In addition, it allowed for the optimization of reservoir management and optimization of hydro cascades, resulting in the better utilization of available hydro potential. Numerous analyses were performed for different stages of system development. These include system configurations that correspond to years 1997, 2001, 2015 and 2020. Additional simulations were performed in order to determine the operational parameters of the three existing hydro power stations Victoria Falls, Kariba, and Kafue Gorge Upper, that correspond to the situation before and after their rehabilitation. The rehabilitation works for these three major power stations, that would bring their operational parameters and availability back to the design level, are planned to be carried out in the period until 2000.

The main results of the hydro operations studies are presented in Table ES-1. These results correspond to VALORAGUA simulations of system configurations in the years 2001 and 2015. The minimum, average, and maximum electricity generation is based on the simulation of monthly water inflows that correspond to the chronological series of unregulated water inflows at each hydro profile in the period from April 1961 to March 1990. The recommended hydrology dataset provided in the Hydrology Report of the SADC Energy Project AAA 3.8 was used for this study.

Table ES-1 Annual Hydro Electricity Production (VALORAGUA Results)

[GWh]

Hydro Power Plant	System Configuration 2001			System Configuration 2015		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Victoria Falls (108 MW)	837.7	853.4	857.8	854.1	856.4	857.8
Kariba (1200 MW)	5909.1	8117.6	9636.6	5645.6	8943.7	10155.7
Kafue G. Upper (900 MW)	2892.7	5215.3	6628.6	4406.3	6641.6	6960.2
Lusiwasi (12 MW)	72.2	95.3	99.7	-	-	-
Cahora Bassa (2075 MW)	10601.3	15143.3	16647.7	14293.3	15898.8	16962.3
Itezhi-Tezhi (80 MW)	-	-	-	141.3	485.9	659.5
Kafue G. Lower (600 MW)	-	-	-	2093.6	3522.5	4385.8
Batoka Gorge (1600 MW)	-	-	-	7807.9	9468.2	11386.0
Lusiwasi (40 MW)	-	-	-	138.3	229.4	274.1

Based on the VALORAGUA simulation results, the operational characteristics of existing and candidate hydro projects were determined for a set of five representative hydrological conditions used in the WASP model. These hydrological conditions and their respective probabilities of occurrence were determined as shown in Table ES–2.

Table ES-2 Hydrological Conditions Used in WASP

Hydro Condition	Probability [%]
Very Dry	10
Dry	13
Average	54
Wet	13
Very Wet	10
TOTAL	**100**

The operational characteristics of hydro power plants that were determined by VALORAGUA hydropower operations studies were transferred into the WASP model for the purpose of least-cost system planning analysis.

The load projections that were used in this study have been developed by EKONO ENERGY and presented in the Twenty Year Power System Development Plan. Two of the EKONO-developed load forecasts (the “most probable” and “high”) were used in this study to represent the range of possible load growth in the future. The low growth projection developed by EKONO, which assumes practically zero load growth over the next twenty years was regarded as too pessimistic.

The high load forecast developed by EKONO was used for the reference (Base Case) scenario. According to this load projection, the peak load is expected to increase from 1,047 MW in FY 1995 to 2,261 MW in FY 2015, which corresponds to an average annual growth rate of 3.9%. The EKONO-developed so-called "most probable" load forecast served to represent a low growth scenario in this study. This forecast assumes a slower growth of system load in the future, which is projected to reach 1,632 MW in FY 2015. The average annual growth rate over the period 1995-2015 corresponds to a modest 2.3%. As EKONO load forecasts did not include the export contracts, in this study both load projections were adjusted for the balance of electricity exports and imports.

Based on the analysis of potential development options and on the discussions with the ZESCO National Team, the five most promising hydro projects were selected to represent candidates for system expansion in the future. These hydro projects are presented in Table ES-3. The cost estimates, in constant U.S. dollars as of the beginning of FY 1995, were determined by an independent World Bank consultant [Karmacharya, 1995] based on the review of feasibility studies and relevant material and labor estimates.

Table ES-3 Hydro Candidates

Name	Installed Capacity [MW]	Overnight Cost 10^6 U.S.$	Overnight Cost $/kW	Construction Time [Years]	Earliest Available Year
Itezhi-Tezhi	80	103.323	1,292.5	3	2001
Kafue G. Lower	450	435.723	726.2	6	2003
Batoka Gorge	800	950.000	1188.0	7	2006
Kariba N. (Ext.)	300	225.038	750.1	3.5	2006
Lusiwasi (Ext.)	40	80.828	2020.7	2	2001

Possible thermal candidates for system expansion were represented by a 150-MW coal-fired generating unit (based on the domestic Maamba coal), and 100-MW gas turbines. The existing coal reserves allow for a maximum one generating unit with the installed capacity of 120-150 MW. This coal-fired candidate unit was modeled with the electrostatic precipitator (ESP) and flue gas desulfurization equipment (FGD). As Zambia is a landlocked country, the import of coal for electricity generation was not considered an economically viable option because of the overland transportation problems and associated costs. Main characteristics of thermal expansion candidates are presented in Table ES-4.

Table ES-4 Thermal Candidates

Candidate Name	Fuel Type	Unit Size [MW]	Fuel Cost [cents/10^6 kcal]	Overnight Cost [$/kW]
COAL	Maamba coal	150	606.	2,096.
GT	Diesel oil	100	2,200.	469.

The economic comparison of hydro and thermal expansion candidates was performed for the study period of 21 years, from FY 1995 to FY 2015. All costs were expressed in constant 1995 U.S. dollars. The discount rate applied for the present worth analysis was 10%, with sensitivity analyses performed for values from 6% to 14%. No real cost escalation was assumed for the domestic Maamba coal, while the World Bank projection of petroleum prices on the international market was used as an assumption for the cost escalation of diesel fuel. The sinking fund depreciation method was used to calculate the salvage value of candidate plants committed during the study period. The economic loading order of existing and candidate generating units was used in all analyzed scenarios. The upper and lower values of the planning reserve margin were specified very wide, exceeding the peak load from 10% to 60%, in order to simulate every possible system configuration that can adequately meet the system demand and reliability constraints. The reserve margin calculation was based on the available system capacity rather than on the installed capacity. The upper limit for the loss-of-load-probability (LOLP) reliability parameter was specified as 1% starting from FY 2003. Sensitivity studies were performed for LOLP values from 0.5% to 3%, and the cases with no LOLP constraints were also examined. The energy-not-served (ENS) cost for the Base Case analysis was estimated at 0.50 $/kWh. Sensitivity analyses were performed for ENS cost estimates in the range from 0.262 $/kWh to 1.25 $/kWh.

The analysis of the long-term system development included four main scenarios based on the high and low load growth projections with and without thermal candidates. In the cases without thermal candidates, the gas turbines were not allowed to compete during the optimization process. These cases represent the "hydro only" development strategy. The least-cost generation expansion paths obtained for the four main development scenarios are summarized in table ES-5.

Table ES-5 Least-Cost Development Paths

Year	Development Scenario			
	Base (High) Load Forecast		Low Load Forecast	
	With Thermal	Hydro Only	With Thermal	Hydro Only
1995				
1996				
1997				
1998				
1999				
2000				
2001	ITT	ITT	ITT	ITT
2002				
2003	KFGL, GT	KFGL	KFGL	KFGL
2004				
2005	GT			
2006	2 x GT	LUSW, BATK	GT	LUSW, BATK
2007				
2008	GT			
2009	GT			
2010	GT			
2011				
2012			GT	
2013				
2014	GT			
2015		KRBX	GT	
PV (1995) of Total Expansion Cost [10^6 U.S.$]	**627.93**	**892.65**	**440.94**	**710.86**

ITT Itezhi-Tezhi (80 MW)
KFGL Kafue Gorge Lower (600 MW)
LUSW Lusiwasi Extension (28 MW)
BATK Batoka Gorge (600 MW)
KRBX Kariba North Extension (300 MW)
GT Gas Turbine (100 MW)

It should be mentioned that least-cost expansion plans obtained for the "hydro only" development scenarios were significantly more expensive than the corresponding expansion plans with thermal candidates. In addition, the reliability of electricity supply was lower than in corresponding scenarios with gas turbines, primarily because of the shortage of hydro energy in the very dry hydrological condition. The selected gas turbines serve mainly as system reserve and perform peaking duties in the period of adverse hydrological conditions. Their utilization factors are very small and range from 2% to 6%. The electricity production and annual capacity factors of gas turbines for the Base Case scenario (high load forecast with thermal candidates) in the period FY 2003-2015 are presented in Table ES-6.

Table ES-6 Operation of Gas Turbines

Fiscal Year	Hydro Power Plants			Gas Turbines		
	Installed Capacity [MW]	Energy Production [GWh]	Capacity Factor [%]	Installed Capacity [MW]	Energy Production [GWh]	Capacity Factor [%]
2003	2338	9375	45.8	100	19.7	2.2
2004	2338	10379	50.7	100	19.8	2.3
2005	2338	11046	53.9	200	44.7	2.6
2006	2338	11911	58.1	400	96.7	2.8
2007	2338	12249	59.8	400	110.2	3.1
2008	2338	12938	63.2	500	165.4	3.8
2009	2338	13656	66.7	600	224.7	4.3
2010	2338	13954	68.1	700	257.5	4.2
2011	2338	13575	66.3	700	226.8	3.7
2012	2338	13990	68.3	700	261.0	4.3
2013	2338	14240	69.5	700	284.0	4.6
2014	2338	14679	71.7	800	355.9	5.1
2015	2338	14879	72.6	800	396.4	5.6

If compared with the total electricity production of the hydro power plants, the thermal generation is very small and amounts to less than 3%. In the actual system operation, the generation of gas turbines could be eventually imported or provided by some other generating facilities, e.g. small hydro power stations. However, the importance of this analysis is to emphasize the fact that besides Itezhi-Tezhi and Kafue Gorge Lower, there will be a need for some additional generating facilities to provide a stable and reliable electricity supply in the periods of adverse hydrological conditions.

The present value of the total system expansion and operating costs over the period FY 1995-2015 for the Base Case development plan amounts to U.S.$627.9 million, expressed in constant 1995 prices. The corresponding expansion plan without thermal candidates is U.S.$264.7 million (or 42.1%) more expensive. Similarly, for the low load forecast, the expansion plan without thermal candidates is U.S.$269.9 million more expensive than the one with thermal candidates.

Conclusions and Observations:

Based on the analysis of different scenarios performed during the study, the main conclusions and observations can be summarized as follows:

- It is very important to proceed with the scheduled rehabilitation works of Victoria Falls, Kariba North, and Kafue Gorge power stations in order to bring their operational characteristics back to design parameters. Their rehabilitation, together with the construction of Itezhi-Tezhi, is expected to help the system to overcome potential shortfall situations in the period until the commissioning of Kafue Gorge Lower. These shortfall situations may occur in the period 1999-2002 in the case of dry or very dry hydrological conditions (their combined probability of occurrence is about 23%).

- As the system reserve margin will rapidly decrease in the period after 2000, the analysis shows that the Itezhi-Tezhi and Kafue Gorge Lower hydro power stations should be developed as early as possible. Both Itezhi-Tezhi and Kafue Gorge Lower proved to be excellent candidates for system expansion in the future, and they were a part of the least-cost solution in practically every scenario that was analyzed.

- Because the electricity production of hydro power plants in the Zambezi river basin is very sensitive to hydrological conditions, the desired level of reliability of supply will be difficult to achieve with the "hydro only" development strategy. The reliability of customer supply is mainly affected by the very dry hydrological condition, in which there is a shortage of hydro generation in the system. The missing energy can be either imported, or produced within the country by small hydro power stations, or generated by peaking thermal units.

- The strengthening of the transmission lines and interconnections with the neighboring countries and SAPP Power Pool should be one of ZESCO's priorities in the future. The improved transmission capabilities will not only improve the reliability of supply of domestic consumers, but will also enable electricity exports during the favorable hydrological conditions.

- The thermal generating units that may be considered for system expansion in the future are gas turbines to perform peaking duties in the periods of adverse hydrological conditions. The gas turbine generating units may also be useful for the electricity supply of the Isolated systems.

- The 150-MW coal-fired generating unit based on the domestic Maamba coal is not an economical option for system expansion in the future.

- Also, the extensions of Lusiwasi and Kariba North power stations were not favorable candidates for system expansion. They were selected by the model into the least-cost expansion plan only in few cases in which no other alternative was available.

- The Batoka Gorge project needs to be studied in more detail in order to determine its economic merit for system expansion.

- The investigation and development of small hydro projects should be accelerated. Besides providing electricity supply to rural areas of the country, small hydro power stations can significantly contribute to the overall reliability of electricity supply in the periods of very dry hydrological conditions.